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Going Beyond Torque

What seem to be minor details in flange assembly can have a significant consequence.

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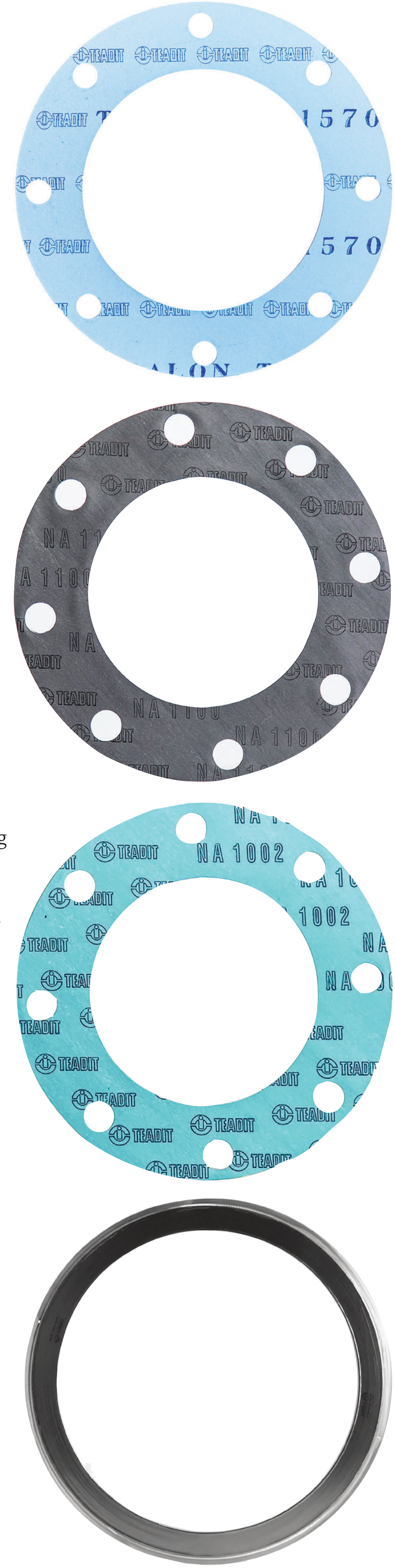


Shown are a number of examples of the types of gaskets tested. From top to bottom: restructured PTFE with microspheres as filler; compressed fiber with aramid filler; compressed fiber with carbon filler; and, a serrated metal gasket. Source (all images: TEADIT

In industrial facilities where pressure-boundary integrity is essential, seemingly minor details in flange assembly can have significant consequences. A gasketed flange joint that is improperly assembled may appear to perform adequately during initial startup, only to leak under normal operating conditions. These leaks are rarely due to the use of flawed materials. More often, they result from inconsistent assembly practices and a lack of understanding of gasket stress behavior.

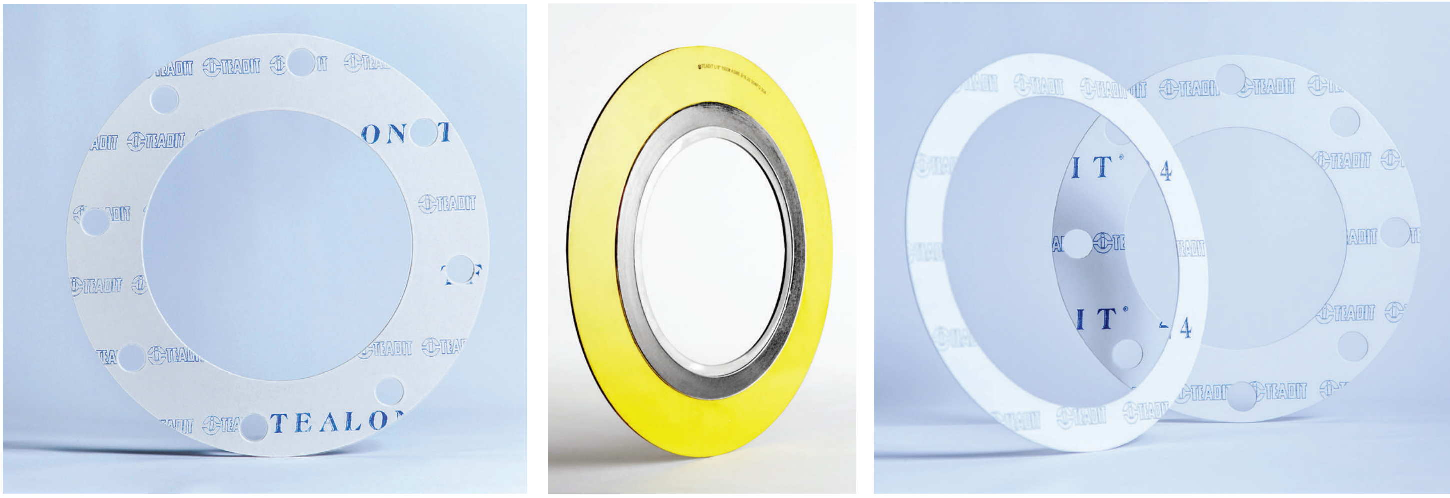
The American Society of Mechanical Engineers (ASME) addressed this long-standing challenge through the development of PCC-1: Pressure Boundary Bolted Flange Joint Assembly.[1] This has since become the industry benchmark for best practices in bolted joint assembly. Within this document, Appendix O plays a central role by providing guidance for determining appropriate assembly bolt stress to ensure that gasketed joints are properly tightened and capable of maintaining sealing stress during long-term operation.

Over the years, manufacturers and research institutions have conducted extensive gasket testing, resulting in a growing body of published performance data. Standards such as EN 13555 have provided a formalized methodology for characterizing gasket properties, and several public databases now make this information accessible.[2] A practical understanding of how to translate this data into PCC-1 Appendix O gasket parameters helps engineers and maintenance teams to make more reliable and data-informed sealing decisions.

ASME PCC-1 and the evolution toward load-based assembly

Historically, bolted flange joints have been assembled using torque-based methods, and this continues to be the most common approach in the field. Many legacy procedures rely on standard torque tables or experience, often without directly accounting for the actual stress applied to the gasket. While torque is convenient to apply and measure, it is only an indirect way of controlling what truly matters for sealability: the gasket stress. Factors such as thread condition, lubrication, bolt length, flange alignment and operator technique can all cause the same torque value to produce very different gasket loads. As a result, simply tightening to a specified torque does not always lead to reliable or consistent sealing performance.

ASME PCC-1 does not reject torque-based assembly. Instead, it highlights the limitations of torque as a proxy for bolt load and encourages practitioners to focus on the gasket stress that is ultimately responsible for sealing performance. PCC-1 provides tools and guidance on torque calculations, tightening sequences and stress targets allowing teams to use torque to achieve consistent gasket stress. In this way, torque becomes a means to an end, rather than the end goal itself. More reliable outcomes are achieved when assembly procedures are designed to control gasket stress, rather than relying solely on torque.



Other gasket types tested included products similar to these from Teadit, left to right: Restructured PTFE with barite as filler; spiral wound gasket; expanded PTFE.

Appendix O builds on this foundation by introducing specific gasket stress limits for different materials and designs. These values help engineers and assemblers ensure that joints are installed within safe and effective stress ranges, improving long-term sealing performance (Fig. 1).

These values serve as a guide for assembling joints with a high degree of repeatability and reliability, which are crucial factors in reducing emissions, minimizing rework and extending the time between planned outages.

The influence of Appendix O on modern assembly practices

The methodology outlined in Appendix O addresses several practical challenges faced by maintenance and reliability professionals: the gasket is only part of the picture. The long-term performance of a gasketed joint depends on whether sufficient load remains on the gasket after it undergoes relaxation and experiences changes due to temperature and internal pressure.

Appendix O guides users toward selecting installation stresses that are high enough to ensure that post-relaxation stress remains above the $Sg_{min\text{-}O}$ threshold. In this sense, $Sg_{min\text{-}S}$ and $Sg_{min\text{-}O}$ are not isolated values, but rather part of a relationship that must be understood and balanced during assembly planning.

For example, a gasket installed with a seating stress of 40 MPa may relax to 25 MPa after exposure to elevated temperature and internal pressure. If the $Sg_{min\text{-}O}$ for that gasket type is 20 MPa, the joint will likely remain tight. If it falls below that threshold, leakage becomes more probable. Appendix O helps practitioners confidently plan for these stress transitions.

Figure 1: Key parameters include:

Sg_{max}	Maximum permissible gasket stress. This value is the maximum compressive stress at the assembly temperature, based on the full gasket area, which the gasket can withstand without permanent damage (excessive leakage or lack of elastic recovery) to the gasket sealing element.
$Sg_{min\text{-}S}$	Minimum gasket seating stress. This is the minimum stress required at assembly to ensure initial seal between the gasket and the flange faces.
$Sg_{min\text{-}O}$	Minimum gasket operating stress. This is the minimum stress that must remain on the gasket after offloading of the gasket by operational loads to ensure that leakage does not occur.
Φ_g	Gasket relaxation fraction. This describes the proportion of the initial load that remains after gasket offload.

Global considerations: EN 13555

While PCC-1 Appendix O defines a framework for determining appropriate gasket parameters, it does not define specific leak rate limits or tightness classes. In contrast, several European standards provide detailed methodologies for evaluating sealing performance and leakage behavior. Notably:

- EN 13555 describes how to determine key gasket parameters such as P_{QR}, $Q_{min(L)}$, $QS_{min(L)}$ and QS_{max} through laboratory testing. These values are linked to defined tightness classes, also defined in the standard.
- VDI 2290 offers general guidance on acceptable leak rates in operational systems and is often used as a practical reference rather than a stringent performance standard. For example, a leak rate of 10^{-2} mg/(s·m) is commonly cited for flanged joints in operation.

Recent technical work has examined the compatibility between the EN 13555 and VDI 2290 and PCC-1 Appendix O, and studies have shown[3] that EN 13555 test data can be used to determine Appendix O values.

For example, EN 13555 defines:

- QS_{max} as *"the maximum surface pressure that may be imposed on the gasket, at the indicated temperature, without collapse or crash,"* which, by definition, is equivalent to Sg_{max}.
- $Q_{min(L)}$ as *"the minimum gasket surface pressure on assembly required at ambient temperature in order to seat the gasket into the flange facing roughness and close the internal leakage channels so that the tightness class is to the required level L for the internal test pressure,"* which is similar to $Sg_{min\text{-}S}$, but PCC-1 does not define a tightness class. In the ►

absence of a definition, VDI 2290 limit of 10^{-2} mg/(s•m) for flanged joints is taken in consideration.

- $QS_{min(L)}$, "as the minimum level of surface stress required for leakage rate class L after off-loading," which is similar to $Sg_{min\text{-}O}$ definition but also lacks the leakage class. Again, VDI 2290 is also considered.
- P_{QR} "as the ratio of the residual and initial gasket stress." Both definitions have the same meaning, so it is possible to get the Φg directly from EN 13555 data for the design temperature.

The alignment between the standards allows end users, gasket manufacturers and engineers to integrate PCC-1-based training and procedures with internationally accepted performance data.

Validating the stress framework: experimental findings

To validate the applicability of EN 13555 data to PCC-1 Appendix O, a structured test protocol was developed, proposed and applied to a range of gasket types commonly used in industry. These included expanded and restructured PTFE gaskets, compressed fiber gaskets, spiral wound gaskets (with graphite filler), and finally, serrated metal gaskets with graphite facing.

For each gasket, a full EN 13555 leakage test was performed. The resulting curves were used to determine the minimum stress required to achieve a leak rate of 10^2 mg/(s•m), or $Q_{min,0.01}$. This value was then adjusted to account for relaxation and internal pressure, using the gasket's stress retention value (Φg) and a simplified formula derived from Appendix O. The result was a calculated minimum assembly stress ($Sg_{min\text{-}S}$), along with a corresponding minimum operating stress ($Sg_{min\text{-}O}$) identified from the unloading curve.

To validate these values in practice, gaskets were installed in test flanges using the calculated $Sg_{min\text{-}S}$, then pressurized to 40 bar of methane. Leak rates were measured at both the initial assembly stress and again after reducing the gasket load to $Sg_{min\text{-}O}$, simulating long-term operating conditions after relaxation.

The tests consistently showed that gaskets assembled using this approach, maintained tightness throughout the experiment. Even after unloading to $Sg_{min\text{-}O}$, leakage remained within acceptable limits, confirming that the EN 13555 derived gasket parameters provided a reliable foundation for Appendix O implementation.

These results validated the accuracy of the proposed calculation method and reinforced the core concept of Appendix O: long-term sealing performance depends not just on how a joint is assembled, but on ensuring that residual gasket stress remains sufficient to maintain a seal under real-world conditions.

Practical implications for maintenance and reliability teams

The use of PCC-1 Appendix O and related standards has practical applications beyond engineering calculations. Maintenance teams and assemblers benefit from understanding the 'why' behind each tightening pattern or torque value. When personnel understand that seating stress must account for relaxation, or that different gasket materials respond differently to load, they are better equipped to avoid costly errors during turnarounds and startup procedures.

Adopting a load-focused approach also supports organizational goals in areas such as:

- Achieving emissions compliance by minimizing fugitive emissions from flanged joint;
- Improving reliability by reducing joint failures and rework;
- Optimizing asset lifecycle planning by allowing longer time between gasket replacement; and,
- Enhancing the safety culture by helping teams identify and address the root causes of joint leakage.

While Appendix O provides the framework, it is the training, communication and validation that are essential to turning that framework into consistent, effective daily practice.

Conclusion

ASME PCC-1 and its Appendix O, have provided the industrial community with a rigorous and practical approach to flange joint assembly. By focusing on gasket stress rather than torque, and by incorporating concepts such as gasket relaxation and minimum operating stress, Appendix O enables more reliable and repeatable assembly practices.

When integrated with internationally accepted testing standards such as EN 13555, the guidance from Appendix O becomes even more powerful. It allows for a harmonized approach to gasket selection, assembly stress determination and joint validation. These are essential for modern plants seeking to reduce leaks, improve safety and meet tightening environmental regulations.

Whether used during shutdown planning, new equipment installation or emissions mitigation efforts, Appendix O provides an essential reference point for those involved in the specification, design and assembly of gasketed bolted flange joints.

References

1. ASME (2022). PCC-1: Pressure Boundary Bolted Flange Joint Assembly. American Society of Mechanical Engineers.

2. https://gasketdata.org/en/index and https://www.esadata.org/.

3. Girão, CD, Veiga, JC, & Meira, I. "Suggested Procedure for Determining the PCC-1 Appendix O Gasket Properties." Proceedings of the ASME 2023 Pressure Vessels & Piping Conference. Atlanta, Georgia, USA. July 16–21, 202 V002T02A002. ASME. https://doi.org/10.1115/PVP2023-106273.

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